NREL Tribology Seminar
Fundamentals of Lubrication
Gear Oil Formulation

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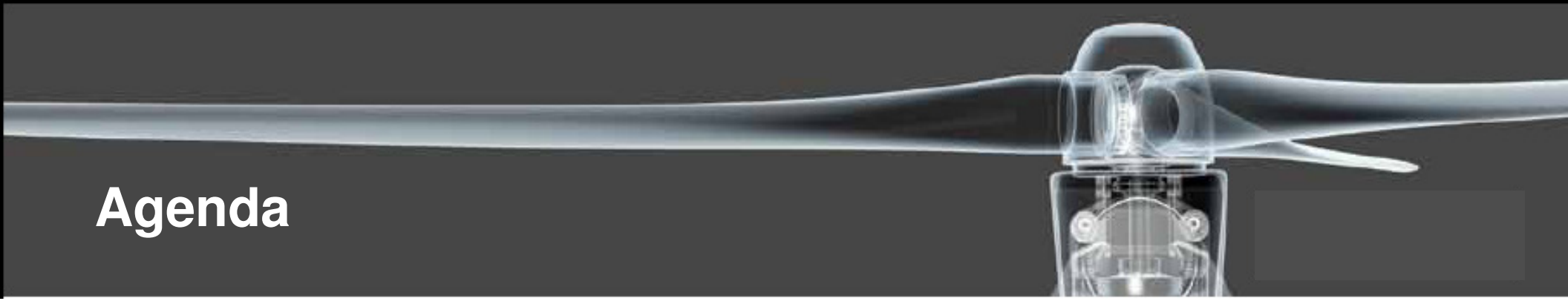
IT S MORE THAN JUST OIL. IT S LIQUID ENGINEERING.

Castrol Industrial



Agenda

- Fundamentals of gear oils
- Application in Wind
- Industrial/ Wind Industry requirements for gear oils
- Composition, effects and side-effects of gear oils and their components
- The general systematic approach of a lubricant development
- Example project
- Summary

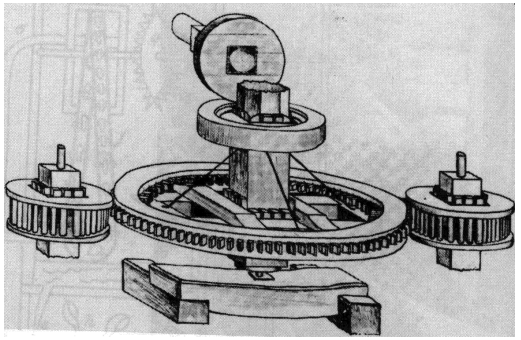
Fundamentals

What is a gear?

Definition:

A Gear is a mechanical device whose function is to transfer rotating motion and power from one part of a machine to another.

So the purpose is to transmit power,change speeds, change direction of rotation

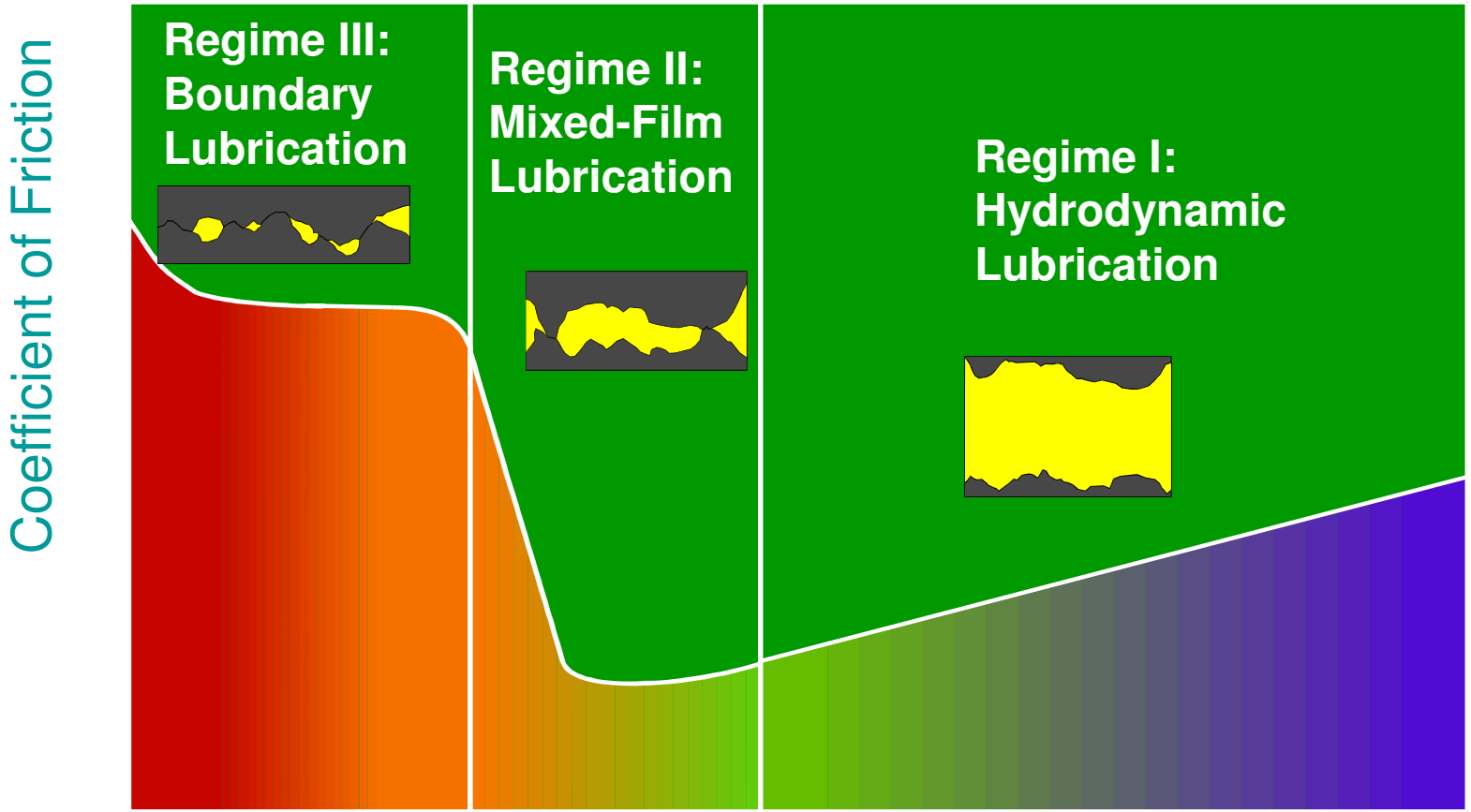


Main purposes of the gearbox oil

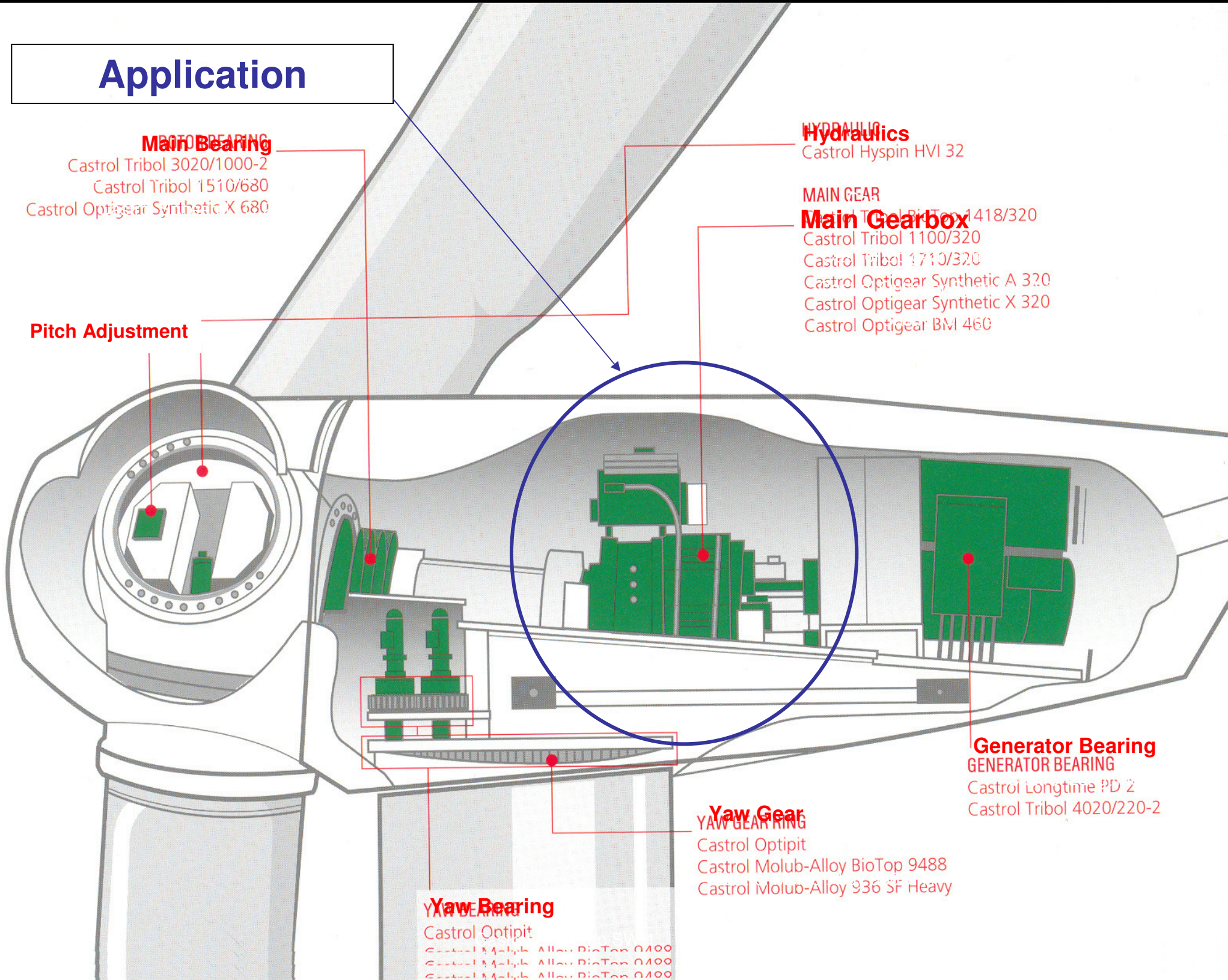
The purpose of a lubricant in general is to separate the rubbing surfaces of the tribo-system from each other to avoid any contact of the asperities.
In case of boundary conditions, the lubricant should be able to avoid wear.

- **Reduce friction**
- **Reduce wear**
- **Cool rubbing surfaces**
- **Seal out / flush away contamination**
- **Prevent corrosion**
- **Dampen shock**

Stribeck Curve and the Lubrication Regimes

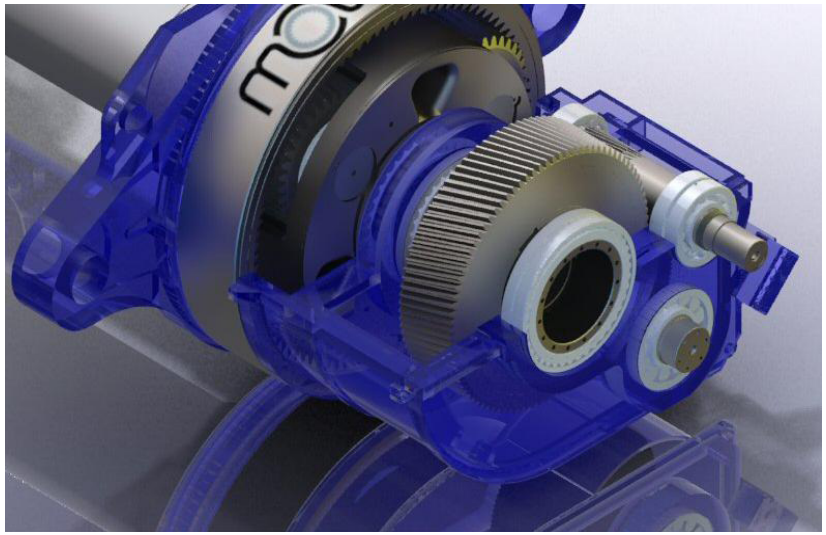


Application



Gear Oil Requirements in Wind Turbines

- **Long oil life** +3 to 5 year minimum
- Use of **Anti-scuff/Anti-wear additives** with high load carrying capacity
  - ✓ Wear performance should remain constant as the oil ages
  - ✓ Micro pitting protection
- **Oil cleanliness** 16/14/11 for new oil 18/16/13 used
- **Wide Temperature Range**
  - ✓ Cold startup
  - ✓ High operating temperatures
- **Oxidation Stability**
  - ✓ Resistance to sludging
  - ✓ No effect on the service intervals of filters
- **Stability with Water/Condensation**
  - ✓ Rust and Corrosion protection



Courtesy of Moventas

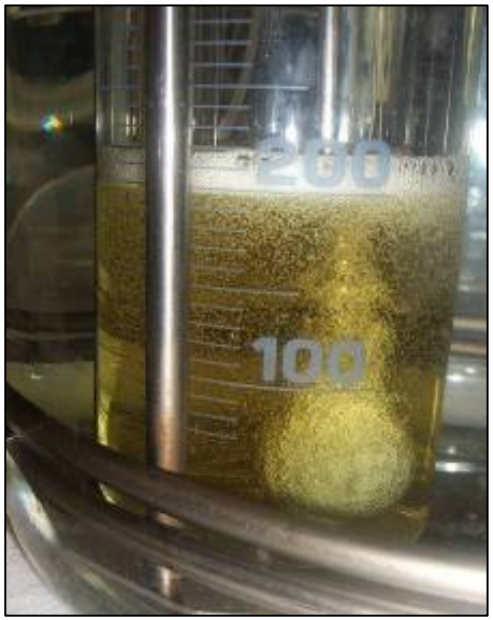
The requirements for gear oils today from Gear box and Turbine manufacturers

- **DIN- minimum requirements** (also changed)
- **Compatibility with elastomers and paints**
  - Static and dynamic tests
  - Long- term tests with a duration of >1000 h
- **Foam tests**
  - Mixed up with anti-corrosion oil
  - after filtration
- **FZG- tests**
  - Micropitting tests
  - Increased loads and/ or tests without running in
- **Tests of antifriction bearings:**
  - Corrosion protection, also under the influence of salt water
  - Formation of residues under the influence of water and temperature
  - Wear tests on FE 8-test-rig
  - Endurance tests on test benches for antifriction bearings
- **Further requirements**
  - Filterability
  - Good cleanliness class and automatic countability (ISO 4406 Particle Count)

Foam Tests

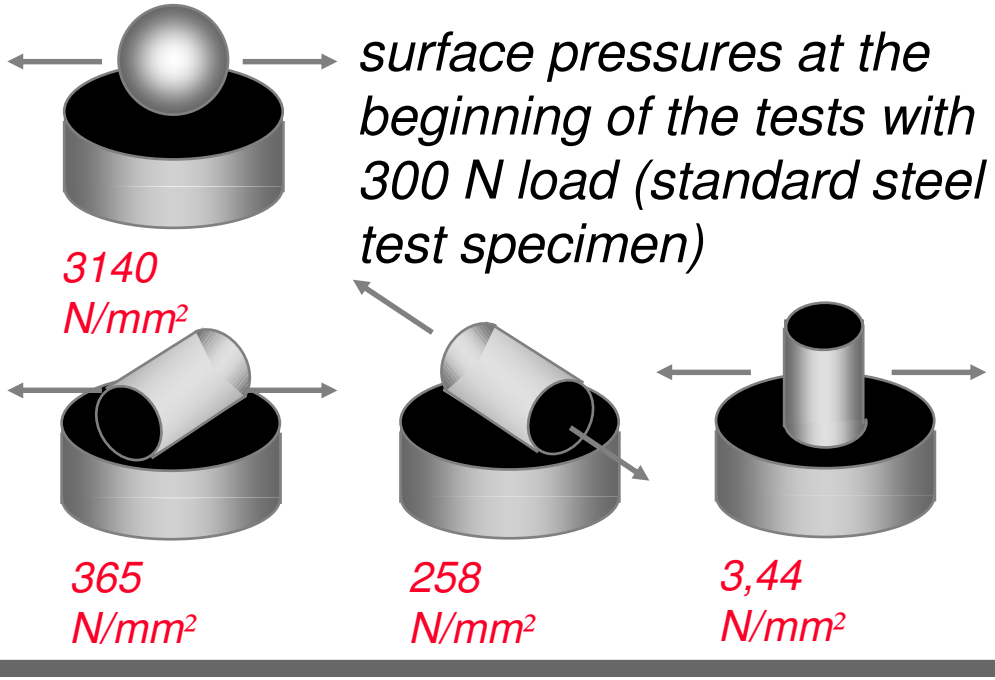
- Usually fresh oils do not tend to foam : < 100 ml
- Causes of foam formation in used oils
  - Contamination with water, dirt, greases, pastes, other oils, over or under filling the reservoir

ISO 6247,
ASTM D 892

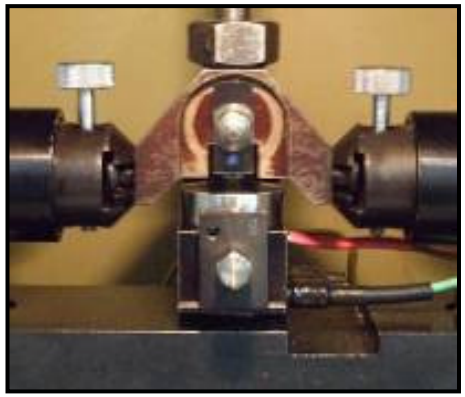


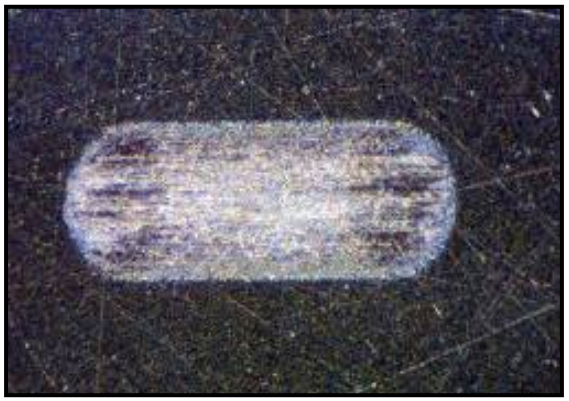
Flender Foam test

SRV-Test- Rig

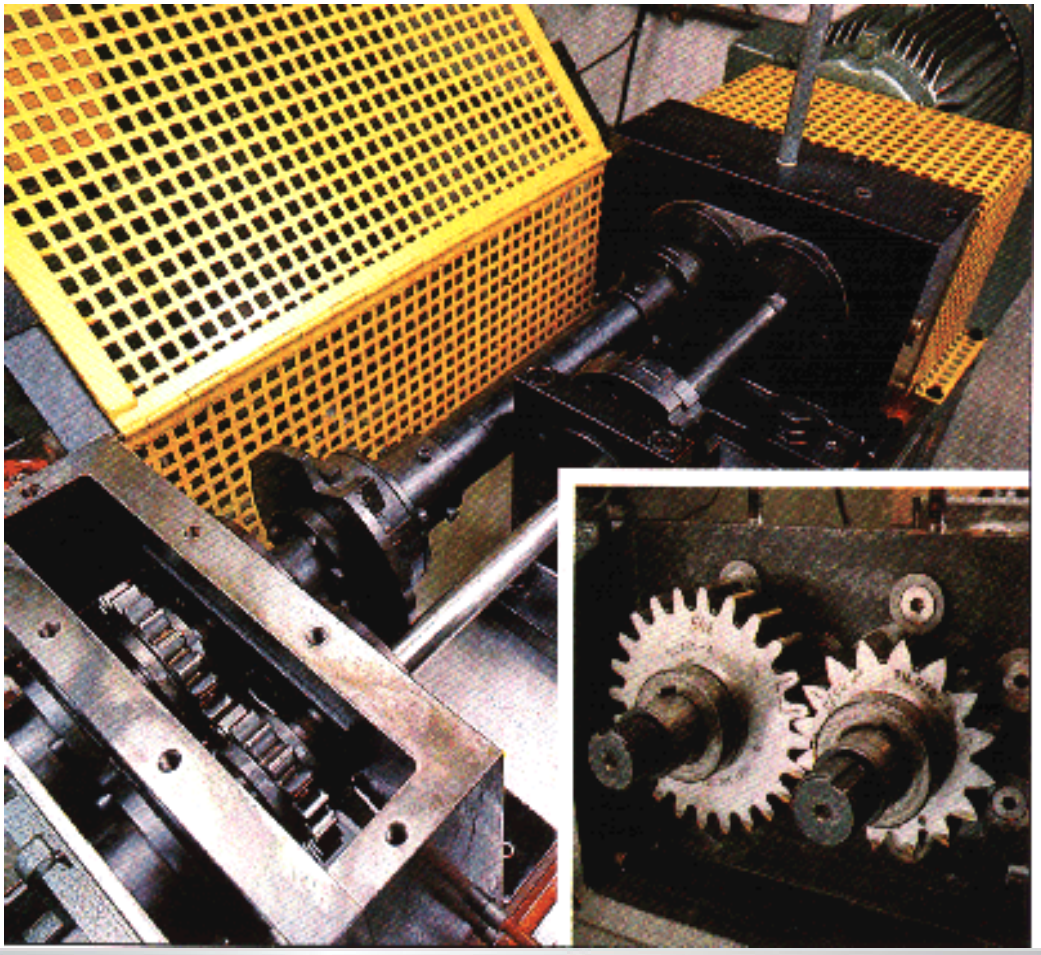

surface pressures at the beginning of the tests with 300 N load (standard steel test specimen)
3140 N/mm²
365 N/mm²
258 N/mm²
3,44 N/mm²


24-002





FZG-Test- Rig

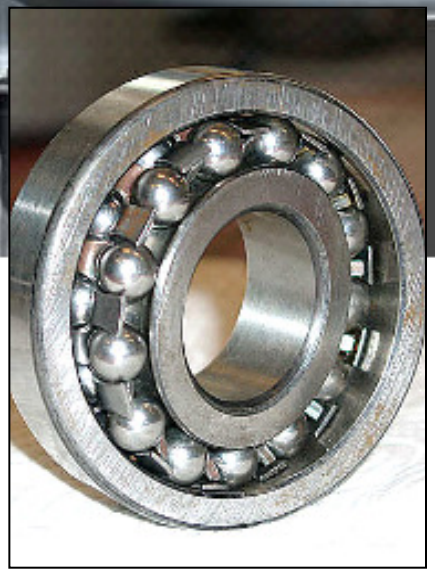


Aim: Determination of load-carrying capacity of lubricants under severe gear conditions. Wear properties can also be tested.

Procedure: Modified test gears are mounted in a gearbox and operated under dip lubrication. Up to 14 stages are applied with increasing load but constant rotational speed and start temperature, until damage to the gear surface
occurs (scoring, scuffing). Each stage requires 15 Min.

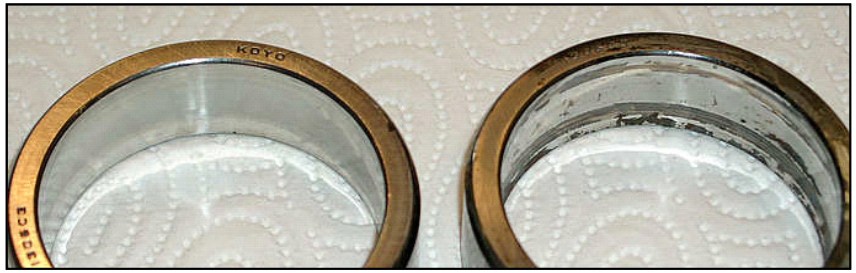
Evaluation: Failure Load Stage refers to the stage at which damage occurs to the pinion surface. When no failure occurs, the load stage is described as >14. CLP gear oils must reach Stage 12

Corrosion tests



Oils
Steel Pin Test

Greases (+ Oils)
Emcor-Test



FE-8 Bearing Wear Test

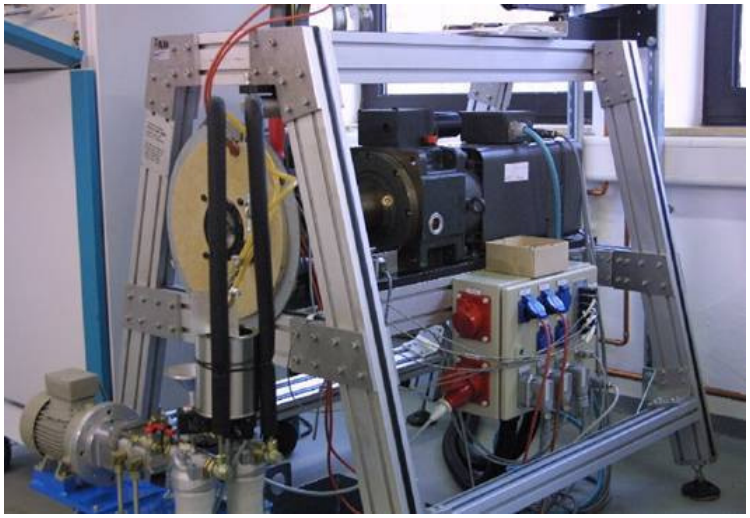
Aim: Determination of wear prevention properties of oils and greases.

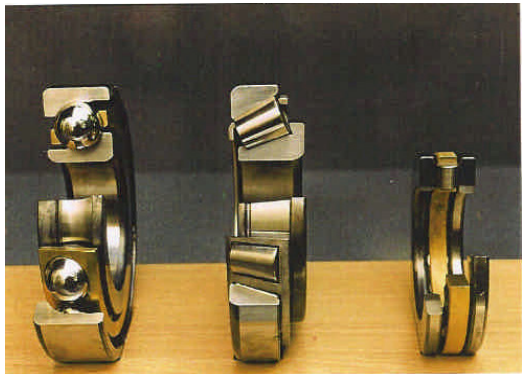
Procedure:

- Antifriction bearings are run under controlled conditions of load, speed and temperature for a defined length of time.
- Mass loss of the bearing parts in the mg range after testing is measured.
- Bearing type and operating conditions may be selected to fit the lubricant being tested.
- Rotational speed ranges from 7,5-3000 rpm; axial load from 10-80kN can be applied.
- Heating or air cooling are possible.

A typical oil test designation D-7,5/100-80 is defined as follows:

- D: bearing type 81212MPB, cylinder roller thrust bearing
- 7,5: rotational speed, rpm
- 100: axial load, kN
- 80: test temperature, ℃





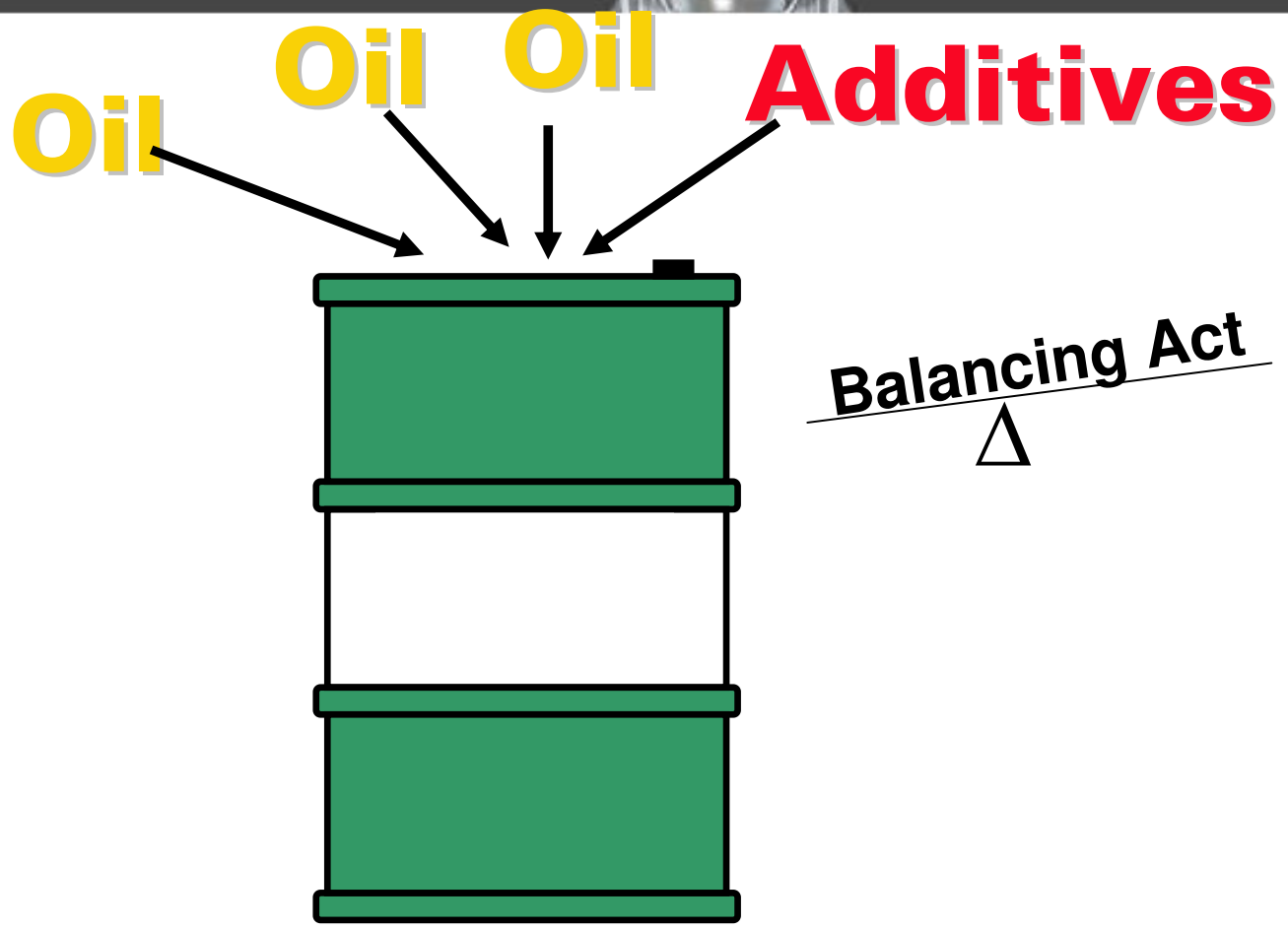
Gear Oil Chemistry in Wind

- Base Oil + Additives
- Base Oils
  - Mineral Oil
  - Synthetic Blend = PAO + Mineral Oil
  - PAO (Synthetic Hydrocarbon)
  - Ester Synthetic
  - PAG

- Additives
  - EP/AW/Micropitting Protection
    - ✓Organo-metallics
    - ✓Ashless
  - Oxidation Inhibitors
  - Rust & Corrosion Inhibitors
  - Pour Point Depressants
  - Anti-Foam

Features, which can be positively influenced by additives

- Wear protection
- Oxidation resistance
- Behavior of viscosity and temperature
- Behavior of foaming
- Corrosion protection
- Adherence
- Water absorbency
- Evaporation losses
- Pour point
- Detergent effects

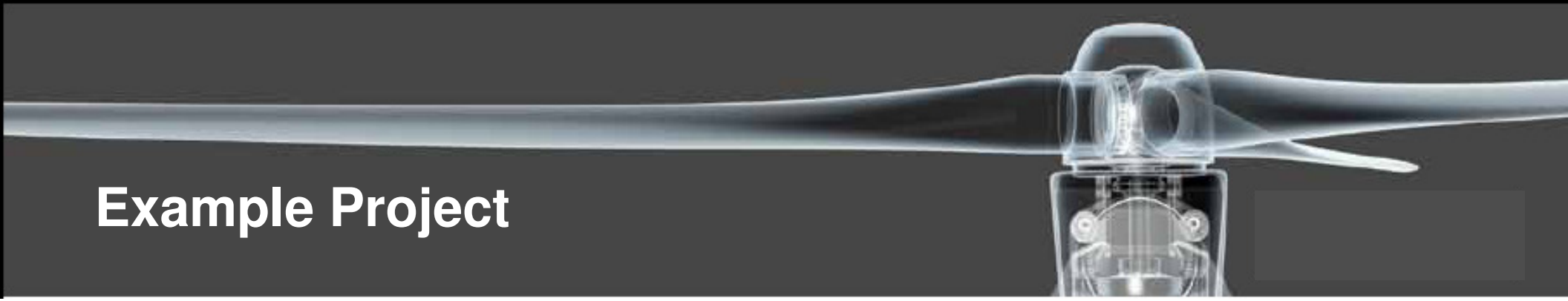


Typical additives and their influence on gear oil formulations

Types of Additives	Improvement	Possible Side Effect
Defoamers	Behavior of foaming	Air release characteristics
Corrosion inhibitors	Corrosion protection	Behaviour of aging
		Behaviour of demulsifying
		Wear behaviour
Detergents / Dispersants	Behavior of detergency	Behaviour of demulsifying
	Behavior of dispersing	Air release characteristics
Oxidation inhibitors	Behavior of aging	Residue formation
VI-Improvers	Behavior of viscosity and temperature	Decreased viscosity / shear-stability
Wear protection additives	Wear behavior	Behaviour of aging
		Compatibility with non-ferrous metals

The general systematic approach of lubricant development

- Defined requirements and correlated test methods
- Combination of choice of raw materials with a test matrix
- Test program starting with basic lab testing and finishing in mechanical tests
- Reiteration if a test fails
- Further tests that could reveal any other advantages/ benchmarking against current existing products for the relevant application
- Field trial



Example Project

- Minimum requirements for a Wind gear oil
- Extremely low friction level
- Excellent corrosion protection - Emcor with synthetic sea water: 0/1 max.
- Low wear rate in bearing wear tests
- Excellent micropitting protection FZG >10
- Suitability for applications in arctic regions – PAO based

Example Project – extract of performance test matrix

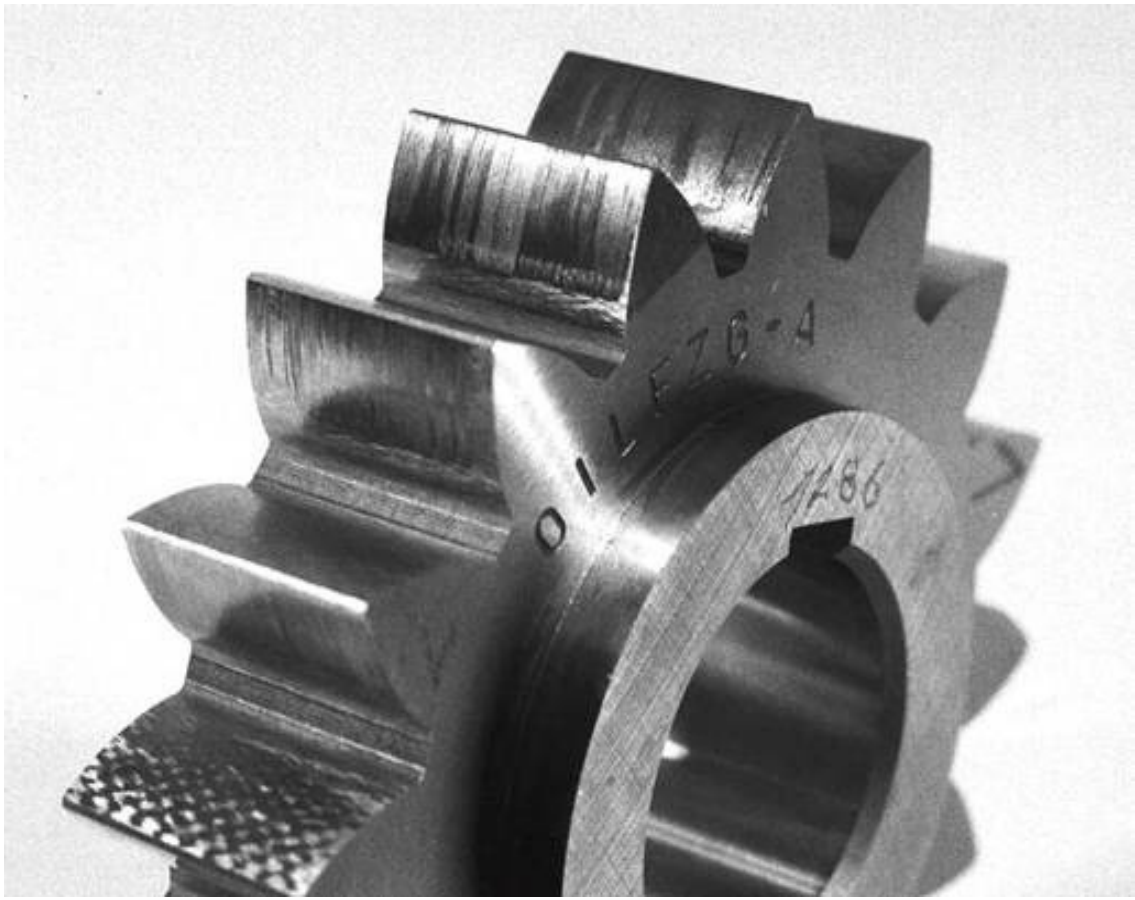
	Specification	PAO 1 PAO 2	PAO 1 PAO 3
kinematic viscosity @ 40 °C	VG 320	pass	pass
kinematic viscosity @100 °C	> 35 mm²/s	pass	pass
VI	>155	152	180
Pour Point	< -40 °C	-36 °C	-45 °C

Example Project – extract of performance test matrix

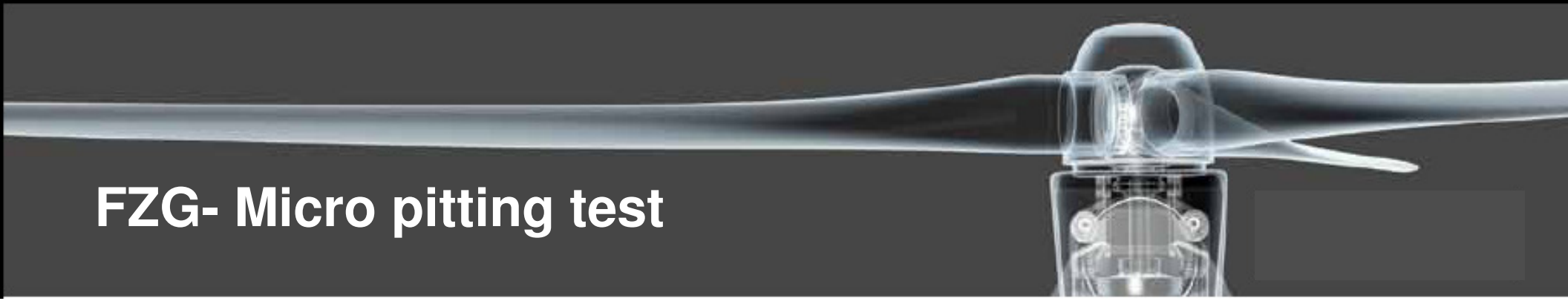
	Specification	Anti-corrosion A	Anti-corrosion B	Anti-corrosion C
rust-prevention characteristics in the presence of water; DIN ISO 7120-A	pass	Pass	pass	pass
rust-prevention characteristics in the presence of water; DIN ISO 7120-B	pass	pass	fail	pass
Emcor Test with 0.5% synth. sea water; mod. ISO 11007	0/1	0/1	NR	0/1

FZG Test-rig – load stage test

FZG-load stage test A/8,3/90		
Load stage	**Hertz Pressure [N/mm²]**	**Requirerd by**
6	927	**HLP DIN 51 524** **Hydraulic oils**
7	1.080	
8	1.232	
9	1.386	
10	1.538	**CLP DIN 51 517.3 gear oils**
11	1.691	
12	1.841	
13	2.001	
14	2.136	



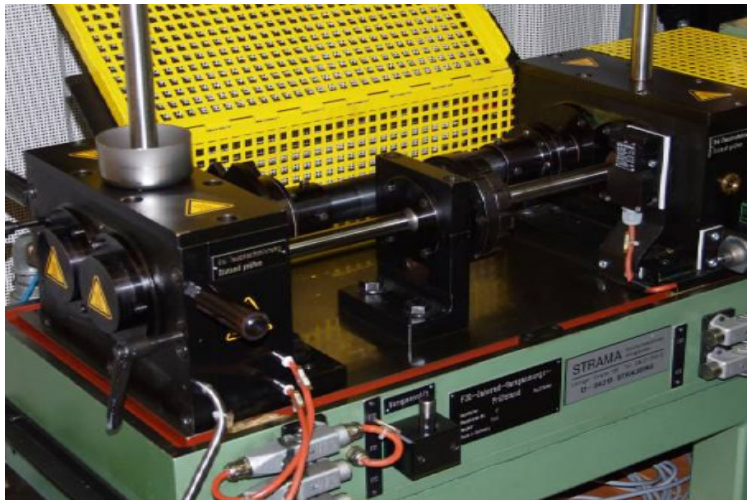
FZG- Micro pitting test



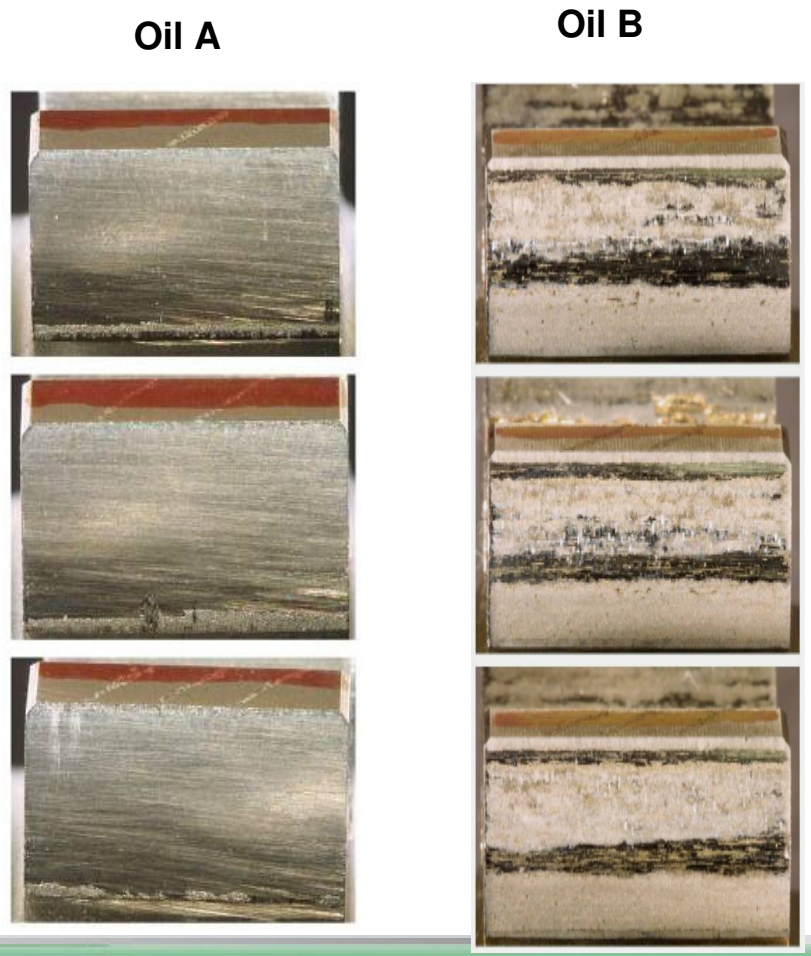
Test-rig:

FZG-Test-rig (Forschungsstelle für Zahnräder und Getriebebau) with gear type C, sensitive for micro-pitting. Circumferential speed at pitch circle 8,3 m/s, Temperature 90°C, arrhythmic roughness R_a of new condition of gears: 0,4 – 0,6 µm.

Used Oils FZG Micropitting Tests



- Micropitting is a surface damage, which occurs when there is high sliding between the gears
- Oil A still rated >10 stages
- Oil B pitting after 3rd of 6 stages



Example Project – extract of performance test matrix

	Specification	**Anticorrosion A**	**Anticorrosion B**	**Anticorrosion C**
SRV friction level	< 0.1	pass	pass	pass
FZG A/8,3/90; DIN ISO 14635	> 14	pass	pass	pass
FZG Micropitting FVA 54	>10	pass	fail	pass

Bearing tests for gear oils

- FE8 standard test to determine wear behaviour at boundary lubrication conditions
  - > at standard load of 80 kN (CLP)
  - > at increased load of 100 kN
- FE8 long-term test to determine fatigue behaviour under mixed friction conditions, 75 rpm
- L11 fatigue test, hydrodynamic lubrication
- FE8 long-term test to determine fatigue behaviour and residue formation at increased temperature/ under the influence of water

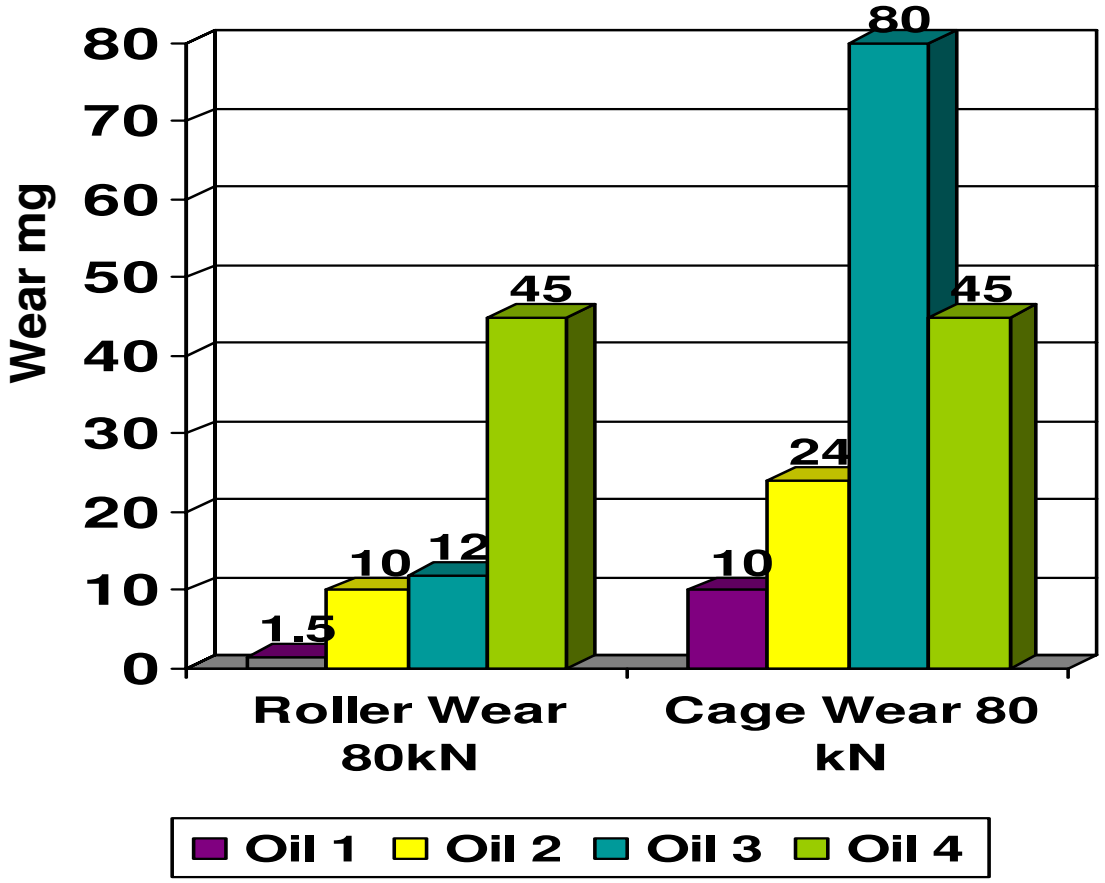
→ **FAG Step 1 to 4 test series**

Example Project – extract of performance test matrix

	Specification	**Anticorrosion A**	**Anticorrosion B**	**Anticorrosion C**
SRV friction level	< 0.1	pass	pass	pass
FZG A/8,3/90; DIN ISO 14635	> 14	pass	pass	pass
FZG Micropitting FVA 54	>10	pass	10	pass
FE 8 wear test D-7,5/100-80 DIN 51819	< 20 mg	pass	25	pass

FE 8 Bearing Wear Test

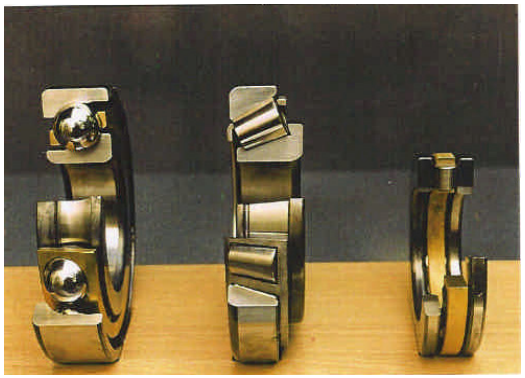
- Bearing lubrication under boundary conditions at 80°C
- High axial loads 80 kN & 100kN
- Low speed 7.5 rpm
- Results may be transferred to practical applications
- Limits for excellent bearing lubricants: roller wear <25 mg, cage wear < 200 mg

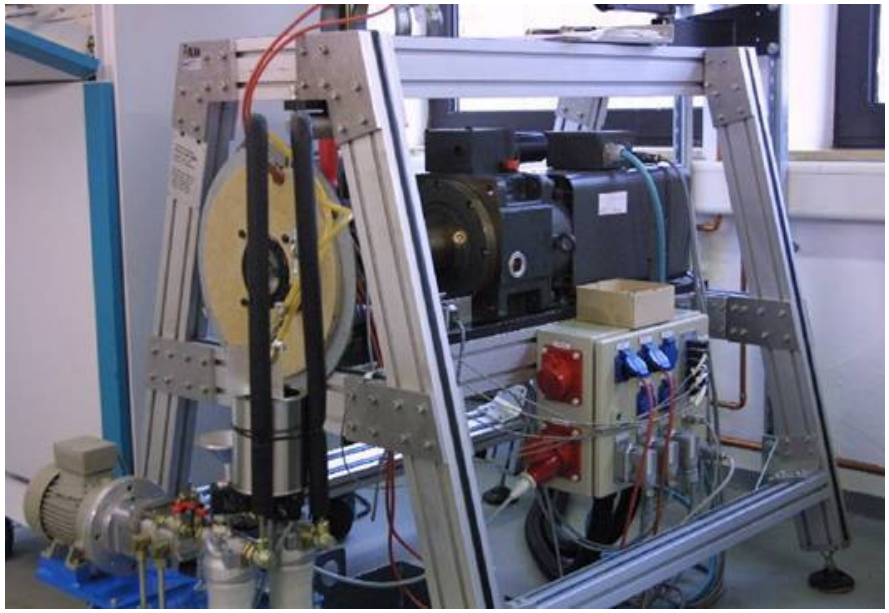


Example project – differentiation of formulations in the FE8 pitting test

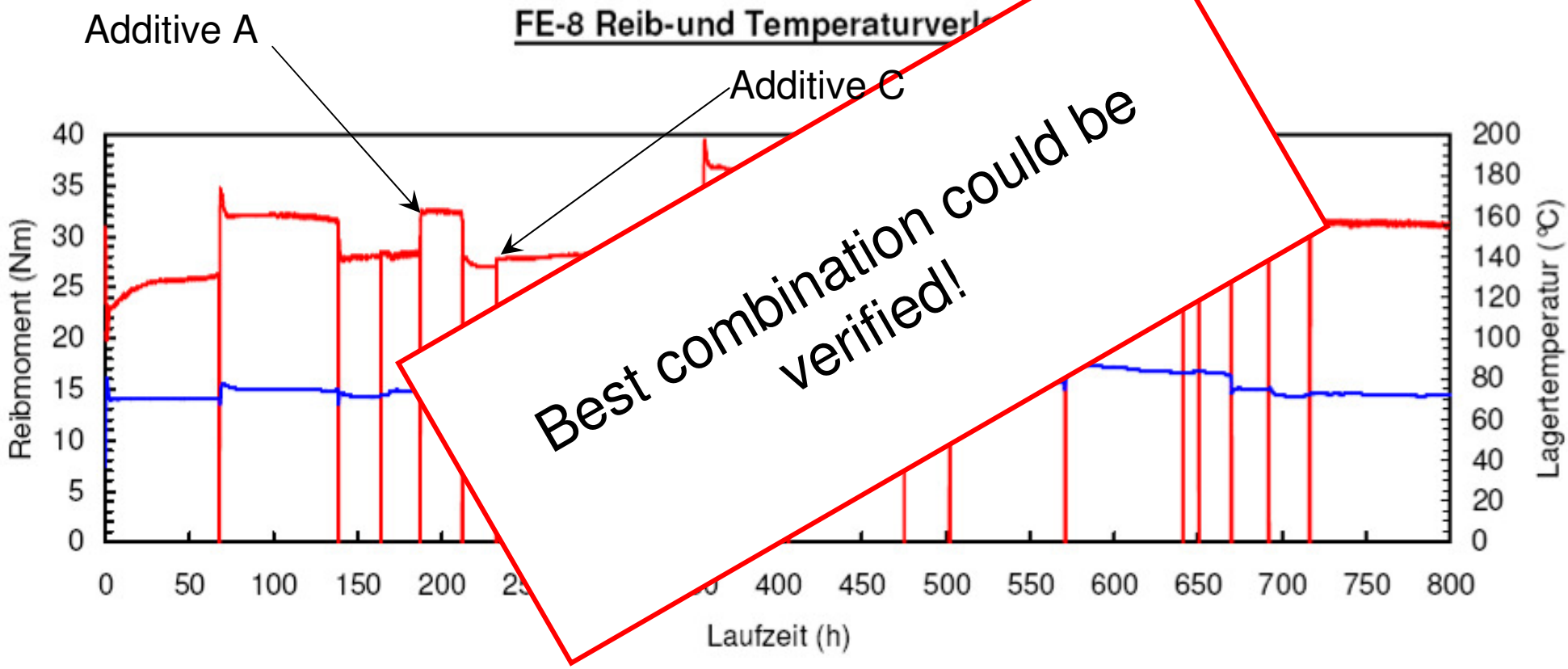
FAG step 2 –

- fatigue behaviour at mixed friction condition
- 800 hrs
- Fax=100 kN
- n=75 rpm
- Temperature=70 °C



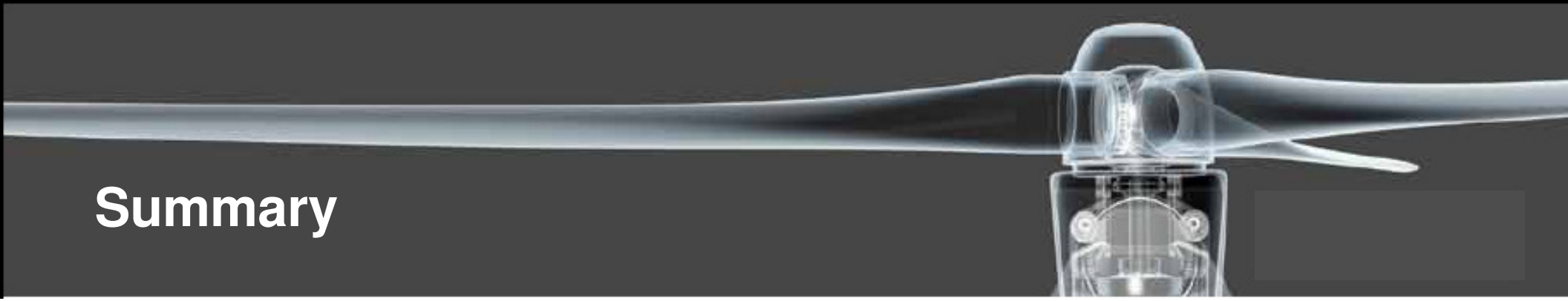


Example Project – differentiation of formulations



Example Project – extract of performance test matrix

	Specification	Anticorrosion A	Anticorrosion B	Anticorrosion C
SRV friction level	< 0,1	pass	pass	pass
FZG A/8,3/90	> 14	pass	pass	pass
FE 8 wear test	<20mg	pass	fail	pass
FE 8 step 2 (mod.) friction screening	Lowest increase of friction torque	+ 5 Nm	fail	+ 1 Nm



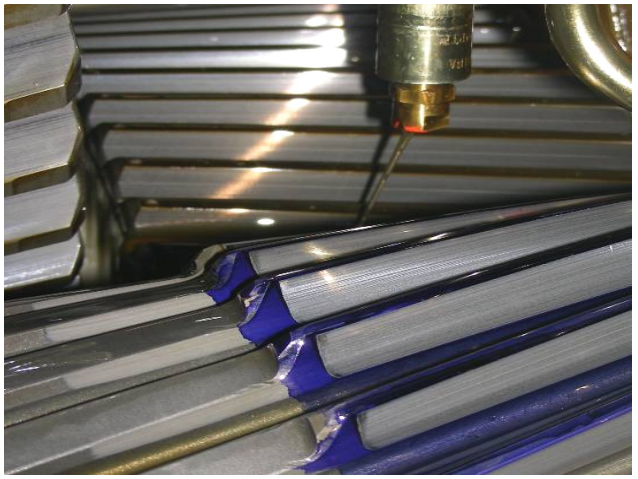
Summary

- The development of lubricants follows a performance test matrix, combining the respective chemistries
- From this matrix and the knowledge about the chemistry of the substances the developer can learn for future combinations or draw conclusions for alternative raw materials
- If formulations perform similar in basic lab tests it is helpful to perform further tests, sometimes in-house methods, to differentiate

Field Test

Field test

- 1 to 2 year test in a gearbox
- Monitor through periodic Oil Analysis trending
  - Oil additives
  - Viscosity
  - Water
- Visual and Borescope inspections
- Used oil testing
  - Run many of the same tests to trend performance changes over time
  - Micropitting, Foaming, Corrosion, Filterability, FE-8
- If all goes well, you have a new product



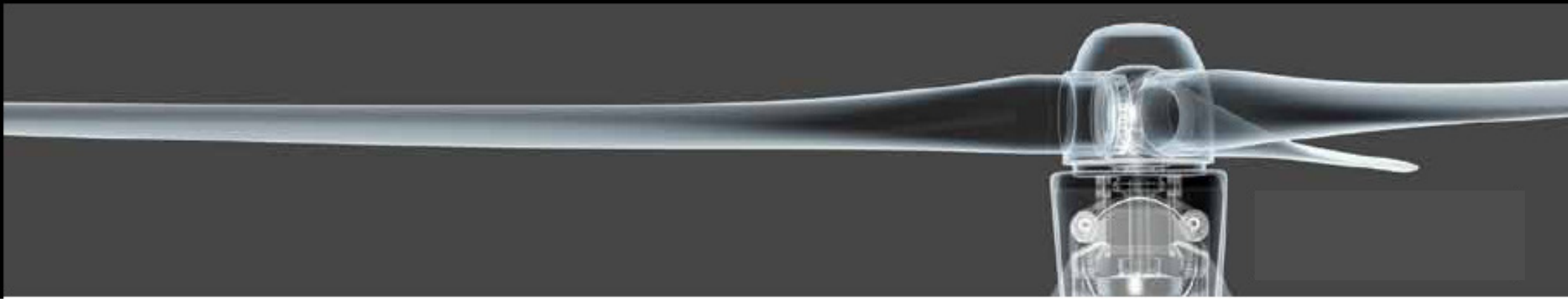
Gear Oil Formulation

- Base Oil + Additives

- It's like baking a cake
- Hopefully you get the right ingredients, correct amounts and proper order!

Balancing Act

Δ



Questions ?